

# Nuclear Materials



*Left: A Leskel Gamma Knife® headframe uses radiation beams to treat people with brain cancer.*

*Middle: NRC staff participates in providing training materials to radiographers at industry event.*

*Right: NRC-licensed teletherapy unit provides treatment to patient.*

The NRC regulates nuclear materials for use in medical, industrial, and academic applications. It also regulates the phases of the nuclear fuel cycle, which begins with the uranium recovery and enrichment facilities that produce nuclear fuel for power plants.

## MATERIALS LICENSES

Through agreements with the NRC, many States have assumed regulatory authority over radioactive materials, with the exception of nuclear reactors, fuel facilities, and certain quantities of special nuclear material. These States are called Agreement States, as shown in gold in Figure 33.

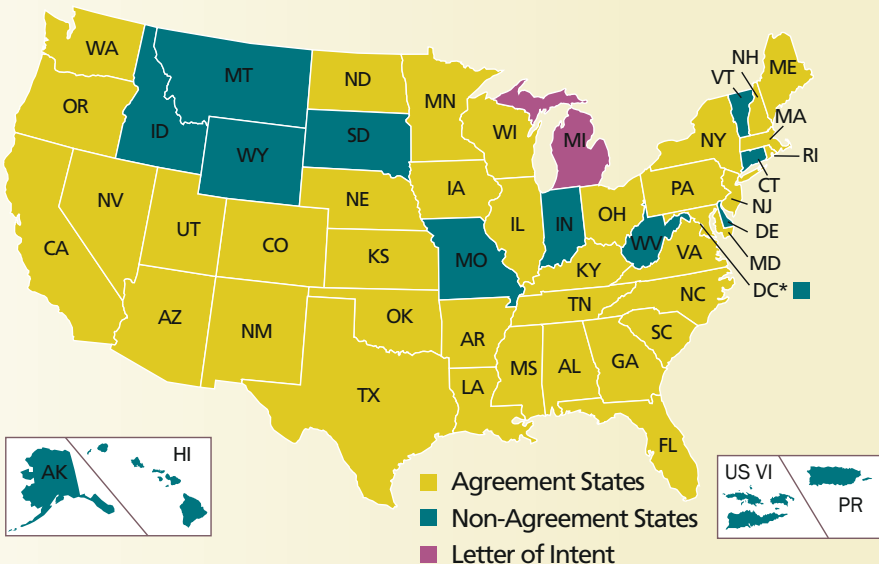
The NRC and Agreement States have issued approximately 22,500 licenses

for general use of nuclear materials (see Figure 33 and Table 11).

- The NRC administers approximately 3,000 licenses.
- 37 Agreement States administer approximately 19,600 licenses.

Reactor- and accelerator-produced radionuclides are used extensively throughout the United States for civilian and military industrial applications; basic and applied research; manufacture of consumer products; academic studies; and medical diagnosis, treatment, and research. The NRC and Agreement State regulatory programs are designed to ensure that licensees safely use these materials and do not endanger public health and safety or cause damage to the environment.


**Figure 33. Agreement States**



\* Includes all major U.S. Territories such as Guam.

**Table 11. U.S. Materials Licenses by State**

Number of Licenses		
State	NRC	Agreement States
Alabama	18	464
Alaska	59	0
Arizona	11	389
Arkansas	6	227
California	50	2,003
Colorado	21	356
Connecticut	182	0
Delaware	60	0
District of Columbia	43	0
Florida	17	1,741
Georgia	16	512
Hawaii	61	0
Idaho	85	0
Illinois	34	796
Indiana	289	0
Iowa	4	174
Kansas	10	305
Kentucky	10	457
Louisiana	12	524
Maine	2	124
Maryland	76	626
Massachusetts	27	507
Michigan	519	0
Minnesota	13	180
Mississippi	6	332
Missouri	299	0

 Agreement State

\* Others include major U.S. territories.

Note: The NRC and Agreement States data are the latest available as of April 2010.

Number of Licenses		
State	NRC	Agreement States
Montana	90	0
Nebraska	5	153
Nevada	4	263
New Hampshire	6	78
New Jersey	41	700
New Mexico	14	185
New York	27	1,449
North Carolina	17	674
North Dakota	10	69
Ohio	43	684
Oklahoma	19	237
Oregon	5	440
Pennsylvania	59	829
Rhode Island	1	50
South Carolina	16	419
South Dakota	44	0
Tennessee	18	603
Texas	47	1,661
Utah	10	193
Vermont	38	0
Virginia	66	427
Washington	19	430
West Virginia	181	0
Wisconsin	20	330
Wyoming	83	0
Others*	162	0
<b>Total</b>	<b>2,975</b>	<b>19,591</b>

## MEDICAL AND ACADEMIC

In both medical and academic settings, the NRC reviews the facilities, personnel, program controls, and equipment to ensure the safety of the public, patients, and workers who might be exposed to radiation.

### Medical

The NRC and Agreement States issue licenses to hospitals and physicians for the use of radioactive materials in

medical treatments. In addition, the NRC develops guidance and regulations for use by licensees and maintains a committee of medical experts to obtain advice about the use of byproduct materials in medicine. The NRC regulations require that physicians and physicists have special training and experience to practice radiation medicine. The training emphasizes safe operation of nuclear-related equipment and accurate recordkeeping. The Advisory Committee on the



*Gamma Knife® used for treating brain tumors.*

Medical Uses of Isotopes comprises physicians, scientists, and other health care professionals who advise the NRC staff on initiatives in the medical uses of radioactive materials.

### Nuclear Medicine

About one-third of all patients admitted to hospitals are diagnosed or treated using radioactive materials. This branch of medicine is known as nuclear medicine, and the radioactive materials for treatment are called radiopharmaceuticals. Doctors of nuclear medicine use radiopharmaceuticals to diagnose patients through in vivo tests (direct administration of radiopharmaceuticals to patients) or in vitro tests (the addition of radioactive materials to lab samples taken from patients). Doctors also use radiopharmaceuticals and radiation-producing devices to treat conditions such as hyperthyroidism and certain forms of cancer and to ease pain caused by bone cancer. In the past

decade, the use of nuclear medicine for treatment and diagnoses has increased significantly.

### Diagnostic Procedures

For most diagnostic procedures in nuclear medicine, a small amount of radioactive material is administered, either by injection, inhalation, or oral administration. The radiopharmaceutical collects in the organ or area being evaluated, where it emits photons. These photons can be detected by a device known as a gamma camera, which produces images that provide information about the organ function and composition.

### Radiation Therapy

The primary objective of radiation therapy is to deliver an accurately prescribed dose of radiation to the target site while minimizing the radiation dose to surrounding healthy tissue. Radiation therapy can be used to treat cancer or to relieve symptoms associated with certain diseases, such as cancer. Treatments often involve multiple exposures spaced over a period of time for maximum therapeutic effect. When used to treat malignant diseases, radiation therapy is often delivered in combination with surgery or chemotherapy.

There are three main categories of radiation therapy:

1. External beam therapy (also called teletherapy) is a beam of radiation directed to the target tissue. There are several different categories of external beam therapy units. The type of treatment machine that is

regulated by the NRC contains a high-activity radioactive source (usually cobalt-60) that emits photons to treat the target site.

2. In brachytherapy treatments, sealed radioactive sources are permanently or temporarily placed near or on a body surface, in a body cavity, directly on a surface within a cavity, or directly on the cancerous tissue. The radiation dose is delivered at a distance of up to an inch (a few centimeters) from the target area.
3. Therapeutic radiopharmaceuticals are quantities of unsealed radioactive materials that localize in a specific region or organ system to deliver a large radiation dose.

### Academic

The NRC issues licenses to academic institutions for educational and research purposes. For example, qualified instructors use radioactive materials in classroom demonstrations. Scientists in a wide variety of disciplines use radioactive materials for laboratory research.

## INDUSTRIAL

The NRC and Agreement States license users of radioactive material for the specific type, quantity, and location of material that may be used. Radionuclides are used in industrial and commercial applications, including industrial radiography, gauges, well-logging, and manufacturing. For example, radiography uses radiation sources to find structural defects in metallic materials and welds. Gauges use radiation sources to determine

the thickness of paper products, fluid levels in oil and chemical tanks, and the moisture and density of soils and material at construction sites. For example, gauges are used to monitor and control the thickness of sheet metal, textiles, aluminum foil, newspaper, copier paper, and plastic as they are manufactured. Gas chromatography uses low-energy radiation sources for identifying the chemical elements in an unknown substance. Gas chromatography can determine the components of complex mixtures, such as petroleum products, smog, and cigarette smoke, and can be used in biological and medical research to identify the components of complex proteins and enzymes. Well-logging devices use a radioactive source and detection equipment to make a record of geological formations down a bore hole. This process is used extensively for oil, gas, coal, and mineral exploration.

### Nuclear Gauges

Nuclear gauges are used as nondestructive devices to measure the physical properties of products and industrial processes as a part of quality control. There are fixed and portable gauges.

A fixed gauge consists of a radioactive source that is contained in a source holder. When the user opens the container's shutter, a controlled beam of radiation hits the material or product being processed or controlled. A detector mounted opposite the source measures the radiation passing through the product. The gauge readout or computer monitor shows the

measurement. The material and process being monitored dictate the selection of the type, energy, and strength of radiation.

Fixed fluid gauges are installed on a pipe that is used by the beverage, food, plastics, and chemical industries to measure the densities, flow rates, levels, thickness, and weights of a wide variety of materials and surfaces.

The diagram on this page shows a portable gauge where the gamma source is placed under the surface of the ground through a tube. Radiation is then transmitted directly to the detector on the bottom of the gauge, allowing accurate measurements of compaction (see Figure 34). Construction industries use such gauges to monitor the structural integrity of roads, buildings, and bridges; explore for oil, gas, and minerals; and airport security uses gauges to detect explosives in luggage at airports.

A portable gauge is a radioactive source and detector mounted together in a

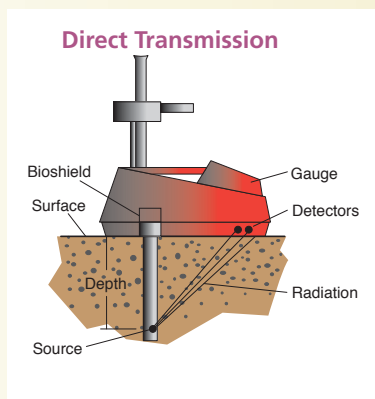
portable shielded device. The device is placed on the object to be measured, and the source is either inserted into the object or the gauge relies on a reflection of radiation from the source to bounce back to the bottom of the gauge. The detector in the gauge measures the radiation, either directly from the inserted source or from the reflected radiation.

The radiation measurement indicates the thickness, density, moisture content, or some other property that is displayed on a gauge readout or on a computer monitor. The top of the gauge has sufficient shielding to protect the operator while the source is exposed. When the measuring process is completed, the source is retracted or a shutter closes, minimizing exposure from the source.

### Commercial Irradiators

Commercial irradiators expose products such as food, food containers, spices, medical supplies, and wood flooring to radiation to eliminate

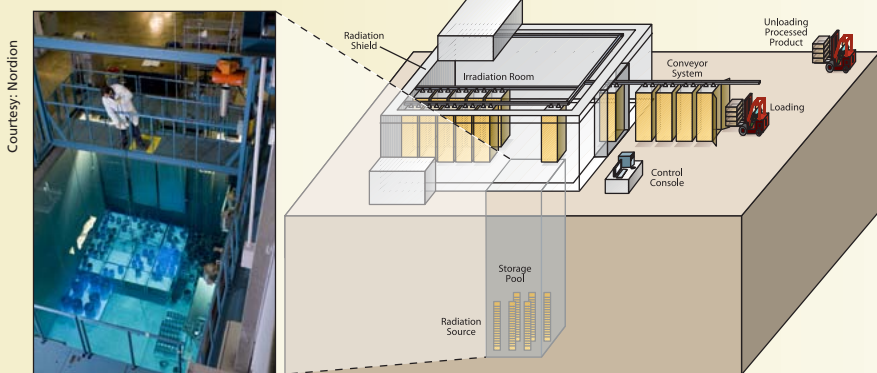
**Figure 34. Moisture Density Gauge**



Courtesy: APNGA

*A moisture density gauge indicates if a foundation is suitable for constructing a building or roadway.*

**Figure 35. Commercial Irradiator**



harmful bacteria, germs, and insects, or for hardening or other purposes (see Figure 35). The gamma radiation does not leave any radioactive residue or cause any of the treated products to become radioactive themselves. The source of that radiation can be radioactive materials (e.g., cobalt-60), an x-ray tube, or an electron beam.

The NRC and Agreement States license approximately 50 commercial irradiators nationwide. For the past 40 years, the U.S. Food and Drug Administration and other agencies have approved the irradiation of meat and poultry, as well as other foods, including fresh fruits, vegetables, and spices. The amount of radioactive material in the devices can range from 1 curie to 10 million curies. Regulations protect workers and the public from radiation involved in irradiation operations.

Generally, two types of commercial irradiators are in operation in the United States: underwater and wet-source-storage panoramic models.

In the case of underwater irradiators, the sealed sources (radioactive material encased inside a capsule) that provide the radiation remain in the water at all times, providing shielding for workers and the public. The product to be irradiated is placed in a watertight container, lowered into the pool, irradiated, and then removed.

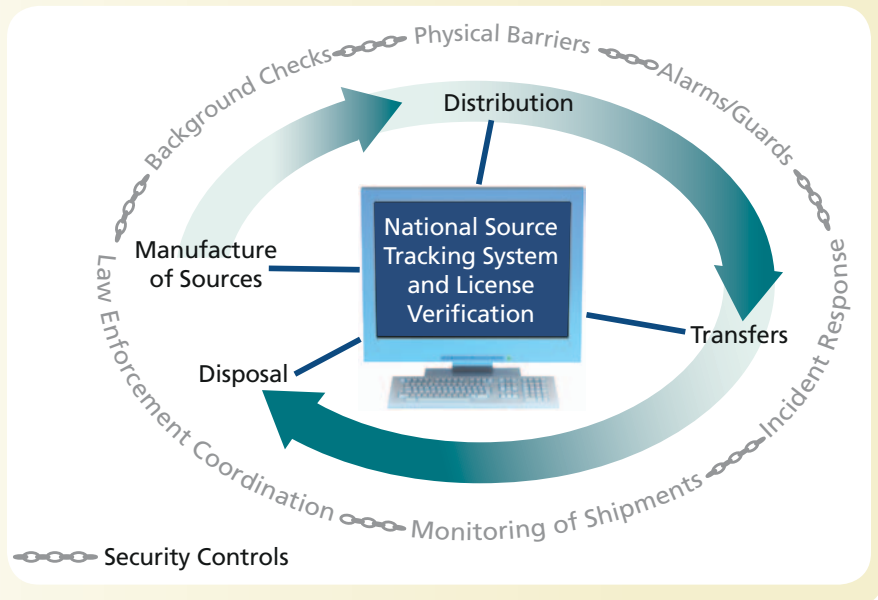
With wet-source-storage panoramic irradiators, the radioactive sealed sources are also stored in the water, but they are raised into the air to irradiate products that are automatically moved in and out of the room on a conveyor system. Sources are then lowered back to the bottom of the pool. For this type of irradiator, thick concrete walls or steel protects workers and the public when the sources are lifted from the pool.

## MATERIAL SECURITY

In January 2009, the NRC deployed its National Source Tracking System (NSTS), by which the agency and its Agreement States track the



**Figure 36. Life Cycle Approach to Source Security**



manufacture, distribution, and ownership of the most high-risk sources. Licensees use the NSTS, a secure Web-based system, to enter up-to-date information on the receipt or transfer of tracked radioactive sources (see Figure 36).

Over the past several years, the NRC and the Agreement States have increased the controls they have imposed on the most sensitive radioactive materials, including physical security requirements and limited personnel access to the materials. Working with other Federal agencies, such as the U.S. Department of Homeland Security, the NRC has also implemented a voluntary program of additional security improvements. Together, these activities will make potentially dangerous radioactive sources even more secure and less vulnerable to terrorists.

### Principal Licensing and Inspection Activities

Each year, the NRC issues approximately 2,700 new licenses, license renewals, and amendments for existing material licenses.

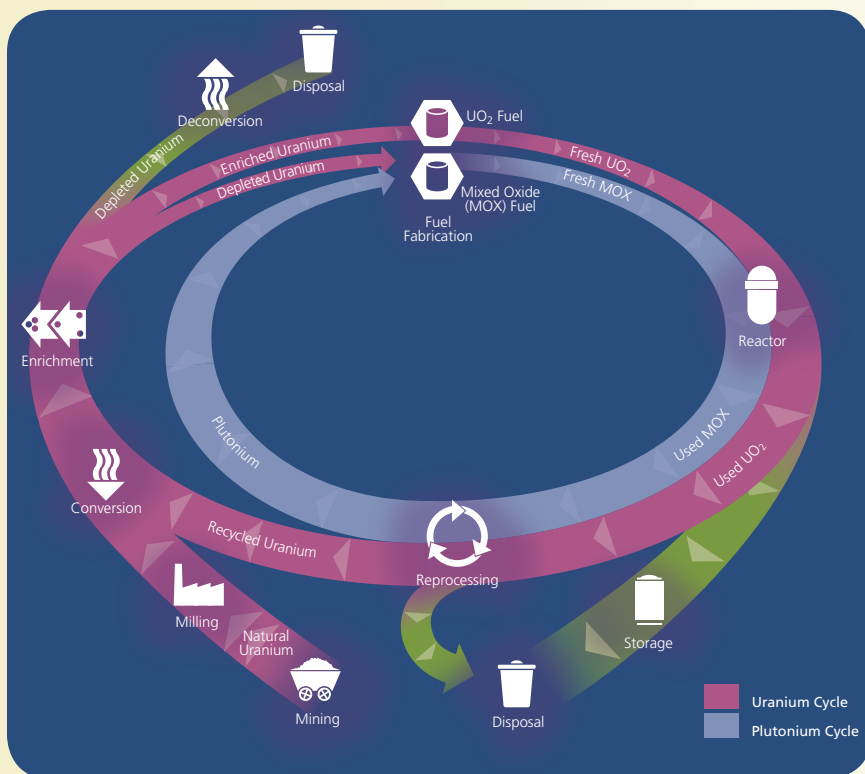
The NRC conducts approximately 1,250 health and safety and security inspections of its nuclear materials licensees each year.

### URANIUM RECOVERY

Figure 37 illustrates the nuclear fuel cycle, which begins with the uranium recovery and enrichment facilities that produce nuclear fuel for power plants. To make fuel for reactors, uranium is recovered or extracted from the ore, converted, and enriched into fuel pellets.



**Figure 37. The Nuclear Fuel Cycle**



The NRC does not regulate traditional mining, but it does regulate the processing of uranium ore. It has jurisdiction over uranium recovery facilities such as conventional mills and in situ recovery facilities.

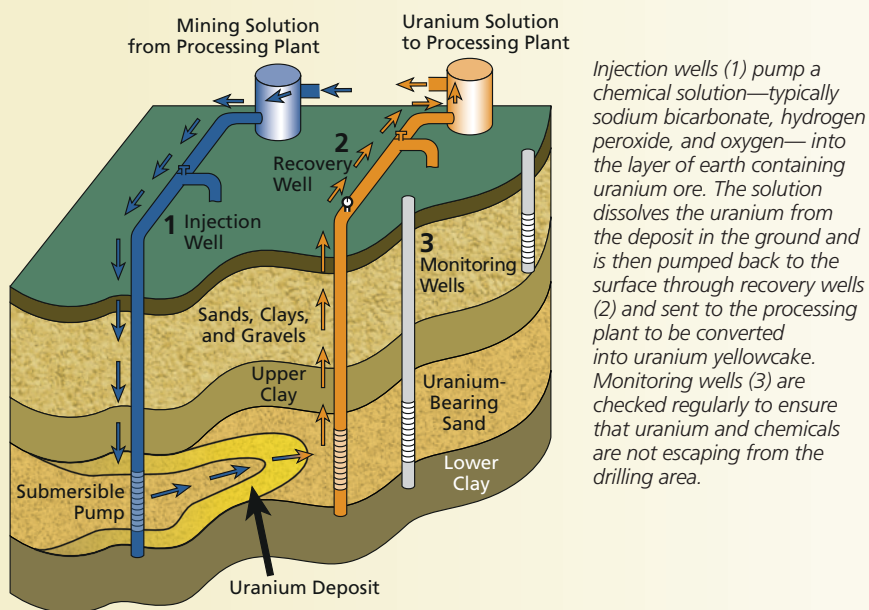
The NRC has a well-established regulatory framework for ensuring that uranium recovery facilities are appropriately licensed, operated, decommissioned, and monitored to protect public health and safety.

### Conventional Uranium Mill

A conventional uranium mill is a chemical plant that extracts uranium

from mined ore. Conventional mills are typically located in areas of low population density, within about 50 kilometers (30 miles) of a uranium mine. The mined ore is transported to the mill, where it is crushed. Sulfuric acid then dissolves the soluble components, including 90 to 95 percent of the uranium, from the ore. The uranium is then separated from the solution, concentrated, and dried to form yellowcake (yellow uranium oxide powder). Of the four remaining conventional mills in the United States, one is operating, while three are in standby status with the potential to restart in the future.

**Figure 38. The In Situ Uranium Recovery Process**

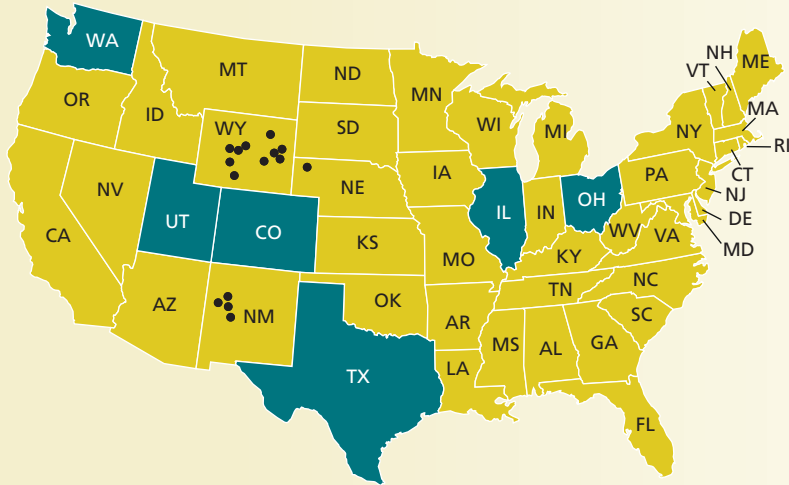


### In Situ Recovery

In situ recovery (ISR) is another means of extracting uranium—this time from underground ore. ISR facilities recover uranium from ores for which recovery may not be economically viable by other methods. In this process, a solution of native ground water typically mixed with oxygen or hydrogen peroxide and sodium bicarbonate or carbon dioxide is injected through wells into the ore to dissolve the uranium. The resulting solution is pumped from the rock formation, and the uranium is then separated from the solution in the same way as a conventional mill, to form yellowcake (see Figure 38). About 12 such ISR facilities exist in the United States. Of these facilities, the NRC licenses four, and Agreement States license the rest (see Figure 39).

Because of the resurgence of interest in the construction of new nuclear power plants, the agency anticipates as many as 25 applications for new uranium recovery facilities and expansions or restarts of existing facilities in the next few years. As of June 2010, the agency had received six applications for new facilities and three applications to expand or restart an existing facility. The current status of applications can be found on the NRC's website (see the Web Link Index). Existing facilities and new potential sites are located in Wyoming, New Mexico, Nebraska, South Dakota, and Arizona, and in the Agreement States of Texas, Colorado, and Utah (see Figure 39 and Table 12). The NRC works closely with stakeholders, including Native American Tribal Governments, to

**Figure 39. Locations of NRC-Licensed Uranium Recovery Facility Sites**



- NRC-licensed uranium recovery facility sites
- States with authority to license uranium recovery facility sites
- States where the NRC has retained authority to license uranium recovery facilities

**Table 12. Locations of NRC-Licensed Uranium Recovery Facilities**

LICENSEE	SITE NAME, LOCATION
<b>In Situ Recovery Facilities</b>	
Cogema Mining, Inc. <sup>o</sup>	Irigaray/Christensen Ranch, WY
Crow Butte Resources, Inc.	Crow Butte, NE*
Hydro Resources, Inc. <sup>o</sup>	Crownpoint, NM
Power Resources, Inc.	Smith Ranch and Highlands, WY*
<b>Conventional Uranium Recovery Facilities</b>	
American Nuclear Corp. <sup>†</sup>	Gas Hills, WY
Bear Creek Uranium Co. <sup>†</sup>	Bear Creek, WY
Exxon Mobil Corp. <sup>†</sup>	Highlands, WY
Homestake Mining Co. <sup>†</sup>	Homestake, NM
Kennecott Uranium Corp. <sup>o</sup>	Sweetwater, WY
Pathfinder Mines Corp. <sup>†</sup>	Lucky Mc, WY
Pathfinder Mines Corp. <sup>†</sup>	Shirley Basin, WY
Rio Algom Mining, LLC <sup>†</sup>	Ambrosia Lake, NM
Umetco Minerals Corp. <sup>†</sup>	Gas Hills, WY
United Nuclear Corp. <sup>†</sup>	Church Rock, NM
Western Nuclear, Inc. <sup>†</sup>	Split Rock, WY

Note: The facilities listed are under the authority of the NRC. For current details on uranium recovery facility applications in review and applications, restarts, and expansions, see Web Link Index.

\* Satellite facilities are located within the State.

† Sites undergoing decommissioning

<sup>o</sup> Cogema has an operating license. Although it is not currently producing, it intends to begin production in 2011.

Kennecott has an operating license, but is in "stand by" mode. Hydro has operating an license, but facility has not yet been constructed.

address concerns with the licensing of new uranium recovery facilities.

The NRC is also responsible for the following:

- Inspecting and overseeing both active and inactive uranium recovery facilities.
- Ensuring that siting and design features of tailings (waste) impoundments minimize disturbance of tailings by natural forces and minimize the release of radon (see Glossary).
- Developing comprehensive reclamation and decommissioning requirements to ensure adequate cleanup of active and formerly active uranium recovery facilities.
- Formulating stringent financial requirements to ensure funds are available for decommissioning.
- Monitoring adherence to requirements for below-grade disposal of mill tailings and liners for tailings impoundments (see Glossary).
- Monitoring to prevent ground water contamination.
- Long-term monitoring and oversight of decommissioned facilities.

## FUEL CYCLE FACILITIES

The basic fuel cycle is the process of turning uranium from the ground into fuel for nuclear reactors. This process includes conversion of the uranium “yellowcake” into uranium hexafluoride ( $\text{UF}_6$ ), enrichment of the uranium in the isotope uranium-235, and fabrication of ceramic fuel pellets. The NRC licenses and inspects all commercial nuclear

fuel facilities involved in conversion, enrichment, and fuel fabrication (see Figures 40–42 and Table 13).

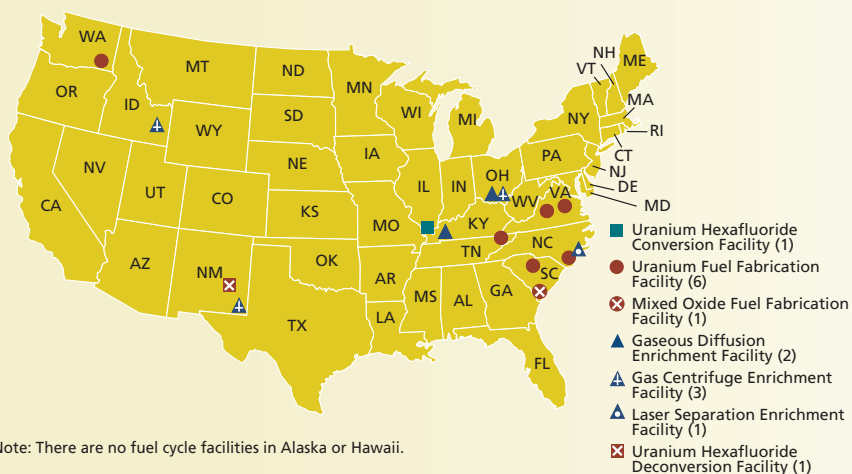
Fabrication is the final step in the process used to produce uranium fuel. Fuel fabrication facilities mechanically and chemically process the enriched uranium into nuclear reactor fuel.

Fabrication begins with the conversion of enriched  $\text{UF}_6$  gas to a uranium dioxide ( $\text{UO}_2$ ) solid. Nuclear fuel is made to maintain both its chemical and physical properties under the extreme conditions of heat and radiation present inside an operating reactor vessel. After the  $\text{UF}_6$  is chemically converted to  $\text{UO}_2$ , the powder is blended, milled, and pressed into ceramic fuel pellets about the size of a fingertip. The pellets are stacked into tubes about 14 feet (2.6 meters) long made of material called “cladding” (such as zirconium alloys). After careful inspection, the resulting fuel rods are bundled into fuel assemblies for use in reactors. The assemblies are washed, inspected, and stored in a special rack until ready for shipment to a nuclear power plant site. The NRC inspects this operation at every step of the process.

The NRC regulates the following:

- One conversion facility
- Four enrichment facilities (one operating, one in cold standby, one operating with further construction, and one under construction)
- Six fuel fabrication facilities
- One mixed oxide fuel fabrication facility (under construction and review)

### Figure 40. Locations of Fuel Cycle Facilities



### Table 13. Major U.S. Fuel Cycle Facility Sites

Licensee	Location	Status
<b>Uranium Hexafluoride Conversion Facility</b>		
Honeywell International, Inc.	Metropolis, IL	active
<b>Uranium Fuel Fabrication Facilities</b>		
Global Nuclear Fuels-Americas, LLC	Wilmington, NC	active
Westinghouse Electric Company, LLC Columbia Fuel Fabrication Facility	Columbia, SC	active
Nuclear Fuel Services, Inc.	Erwin, TN	active
AREVA NP, Inc. Mt. Athos Road Facility	Lynchburg, VA	active
B&W Nuclear Operations Group	Lynchburg, VA	active
AREVA NP, Inc.	Richland, WA	active
<b>Mixed Oxide Fuel Fabrication Facilities</b>		
Shaw AREVA MOX Services, LLC	Aiken, SC	in construction, operating license under review
<b>Gaseous Diffusion Uranium Enrichment Facilities</b>		
USEC Inc.	Paducah, KY	active
USEC Inc.	Piketon, OH*	in cold standby
<b>Gas Centrifuge Uranium Enrichment Facilities</b>		
USEC Inc.	Piketon, OH	in construction
Louisiana Energy Services (LES-URENCO)	Eunice, NM	active**
AREVA Enrichment Services	Idaho Falls, ID	under review
<b>Laser Separation Enrichment Facility</b>		
GE-Hitachi	Wilmington, NC	under review
<b>Uranium Hexafluoride Deconversion Facility</b>		
International Isotopes	Hobbes, NM	under review

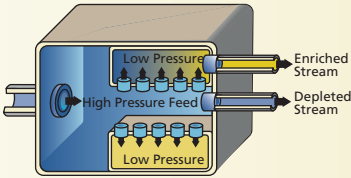
\* Currently in cold shutdown and not used for enrichment.

\*\* Partially operating and producing enriched uranium while undergoing further phases of construction.

Note: The NRC regulates nine other facilities that possess significant quantities of special nuclear material (other than reactors) or process source material (other than uranium recovery facilities). Data as of July 2010.

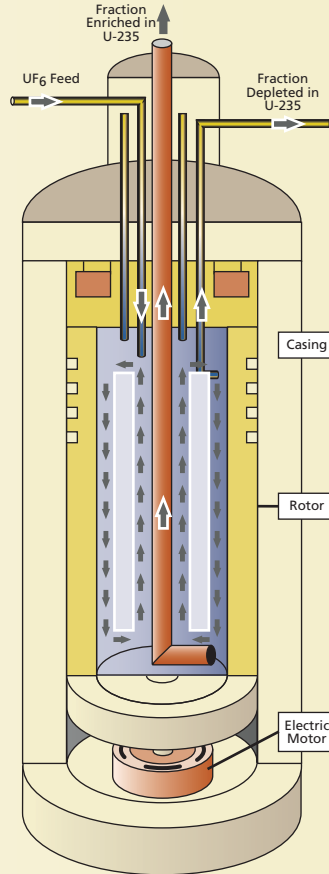
**Figure 41. Enrichment Processes**

**A. Gaseous Diffusion Process**



**A.** The gaseous diffusion process uses molecular diffusion to separate a gas from a two-gas mixture. The isotopic separation is accomplished by diffusing uranium, which has been combined with fluorine to form uranium hexafluoride ( $\text{UF}_6$ ) gas, through a porous membrane (barrier) and using the different molecular velocities of the two isotopes to achieve separation.

**B. Gas Centrifuge Process**



**B.** The gas centrifuge process uses a large number of rotating cylinders in series and parallel configurations. Gas is introduced and rotated at high speed, concentrating the component of higher molecular weight towards the outer wall of the cylinder and the lower molecular weight component toward the center. The enriched and the depleted gases are removed by scoops.

The NRC is also reviewing applications for two enrichment plants and a deconversion facility. The deconversion facility, if approved, would process the depleted uranium from an enrichment facility and convert the material into a uranium oxide and commercially resalable products.

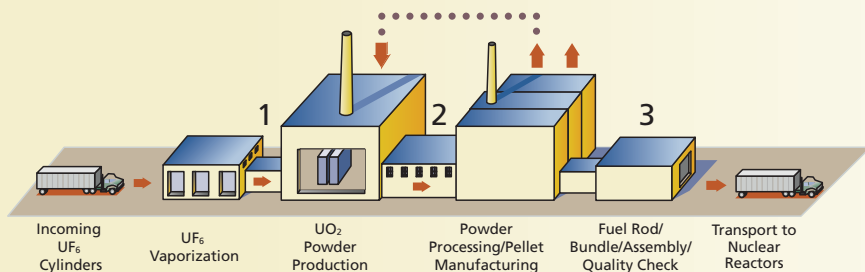
**Domestic Safeguards Program**

The NRC's domestic safeguards program for fuel cycle facilities and

transportation is aimed at ensuring that special nuclear material (such as plutonium or enriched uranium) is not stolen for possible malevolent uses. The program also works to ensure that such material does not pose an unreasonable risk to the public from radiological sabotage.

The NRC verifies through licensing and inspection activities that licensees apply safeguards to protect special nuclear material. Additionally,

**Figure 42. Simplified Fuel Fabrication Process**



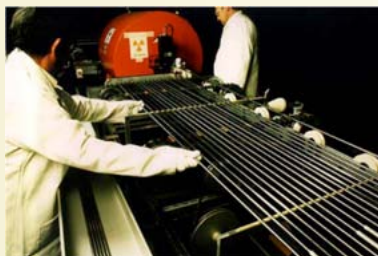
*Fabrication of commercial light-water reactor fuel consists of the following three basic steps:*

- (1) the chemical conversion of  $UF_6$  to  $UO_2$  powder*
- (2) a ceramic process that converts  $UO_2$  powder to small ceramic pellets*
- (3) a mechanical process that loads the fuel pellets into rods and constructs finished fuel assemblies*

**Figure 43. Fuel Pellets**



*(Left) Small ceramic fuel pellets. (Right) Fuel pellets being assembled into fuel rods.*



the NRC and U.S. Department of Energy (DOE) developed the Nuclear Materials Management and Safeguards System (NMMSS) to track transfers and inventories of special nuclear material, source material from abroad, and other material.

The NRC has issued licenses to approximately 180 facilities authorizing them to possess special nuclear material in quantities ranging from a single kilogram to multiple tons. These licensees verify and document their inventories in the NMMSS database. The NRC or State governments license several hundred additional sites that possess special nuclear material in smaller quantities (typically ranging from one gram to tens of grams).

Licensees that possess small amounts of special nuclear material are now required to confirm their inventory annually in the NMMSS database. Previously, those licensees reported transfers of material but not annual inventories.

### Principal Licensing and Inspection Activities

On average, the NRC completes approximately 80 new licenses, license renewals, license amendments, and safety and safeguards reviews for fuel cycle facilities annually.

The NRC routinely conducts safety, safeguards, and environmental protection inspections at all fuel cycle facilities.



